MODELING OF THE CURRENT PROFILE EVOLUTION DURING THE ERS MODE IN TFTR

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Current profile evolution in reverse shear discharges in TFTR

Goals:

- **Compare TFTR and DIII-D current profile evolution in reverse shear discharges**
  - **Current evolution due to neoclassical resistivity agrees well with data from TFTR, DIII-D**
  - **Full neutral beam and bootstrap current have been included**

- **Benchmark codes (Corsica, TRANSP, EFIT, etc.) against one-another**
  - **High pressure ERS discharges (TFTR) show MHD differences between Corsica, TRANSP (especially with VMEC MHD package)**

- **Improve physics models in the codes, e.g. transport and current drive.**
  - **Improved neutral beam current drive model implemented in Corsica**

- **Apply the codes to predict operation of the two tokamaks**
  - **No detailed predictions to date**

Participants

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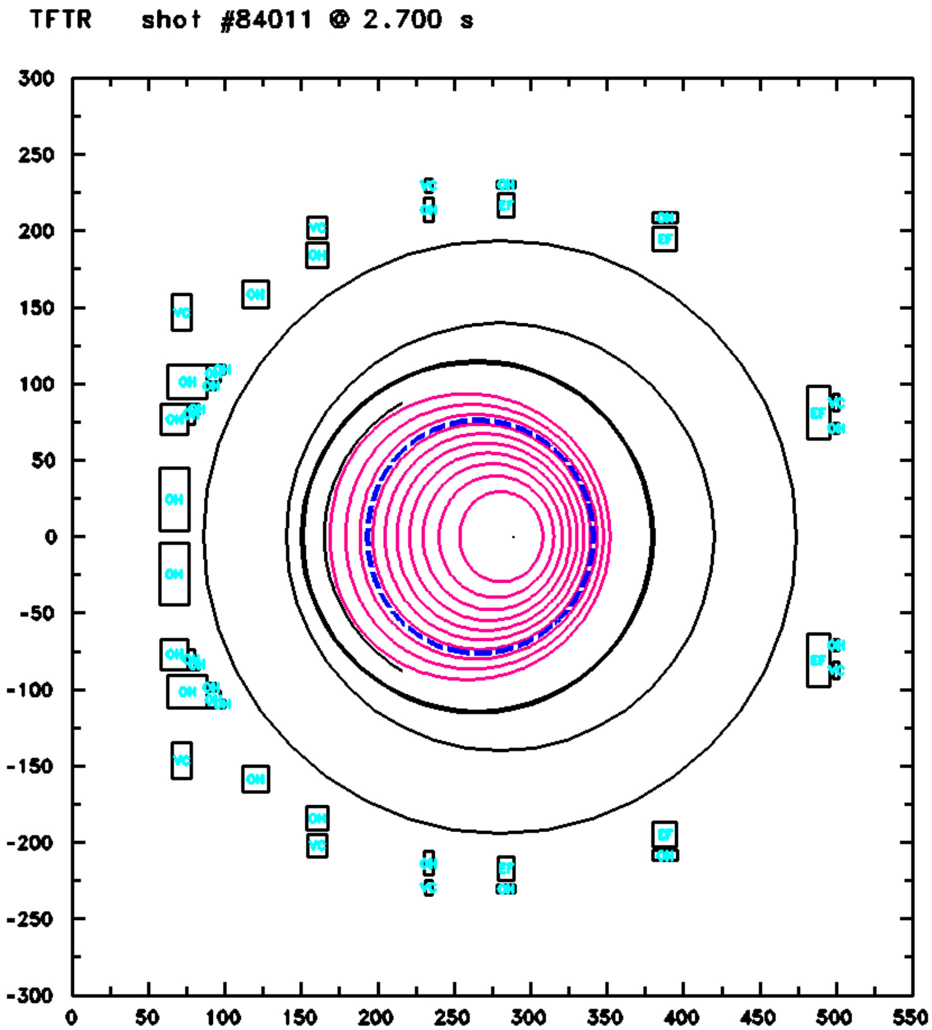
The evolution of the current profile in reversed-shear discharges in TFTR has been successfully modeled by the CORSICA code

For the analyses shown here, we use the data from the TFTR discharge #84011, which was described in F. W. Levinton, et al., "Improved Confinement with Reversed Magnetic Shear in TFTR," Phys. Rev. Letters 75, 4417 (1995).

We have used these calculations to:

- **Show that the behavior of the MHD equilibrium near the magnetic axis must be treated carefully**
- **Verify that the current profile evolution is predicted well by calculated neoclassical resistivity, current drive due to neutral beams, and bootstrap current. (Density and temperatures are taken from the data.)**

DIII-D is also successfully modeled — See T. A. Casper, et al., "Corsica Time-Dependent Modeling of DIII-D Discharges," poster 8Q-16



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Model of TFTR used in the CORSICA calculations. Shown are the poloidal and toroidal field coils, the vacuum system wall, the inner limiter, and flux surfaces corresponding to TRANSP run 84011W03 at 2.7 seconds. Note that the plasma is in contact with the inner limiter at a single point.

CONCLUSION 1 – The q-profile near the axis is sensitive to the MHD assumptions for high pressure, reversed shear discharges

- In TRANSP, the VMEC MHD option uses an expansion in toroidal flux, whereas the VMOMS MHD option uses an expansion in the square-root of the toroidal flux

- Corsica-TEQ uses spline fits in the square-root of the toroidal flux

- For reversed-shear, highly peaked pressure discharges:

The VMOMS and Corsica calculations yield the same Shafranov shifts (for given pressure and current profiles)

The VMEC calculations have significant differences with these, apparently because the assumed analytic behavior near the magnetic axis requires a fine grid to give accurate, quantitative results for high-pressure, reversed-shear operation

Comparisons between TFTR data and calculations

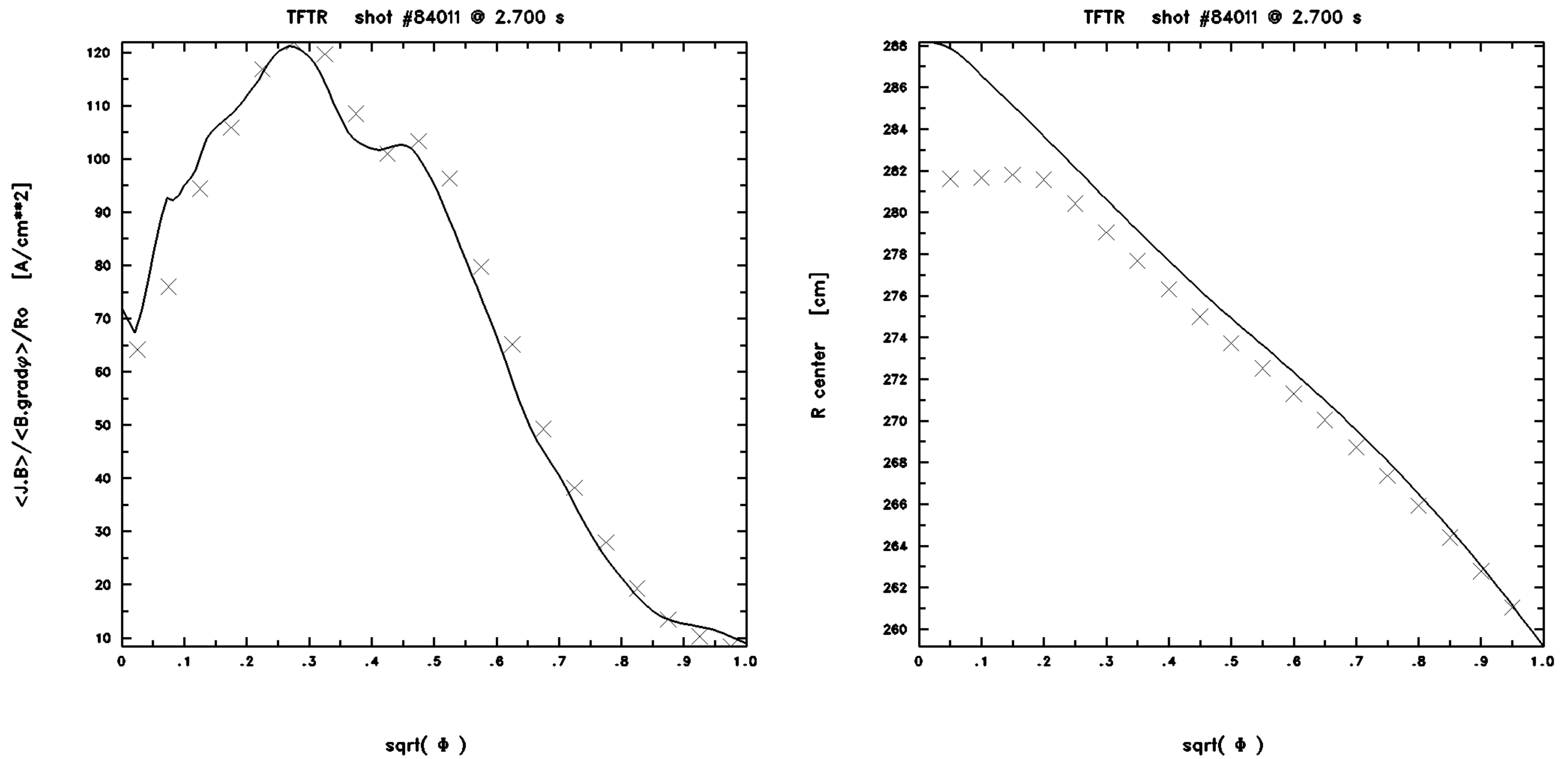
TFTRdata (processed by TRANSP) — crosses (×)

CORSICA calculations — solid lines

Calculated current density, flux-surface centers

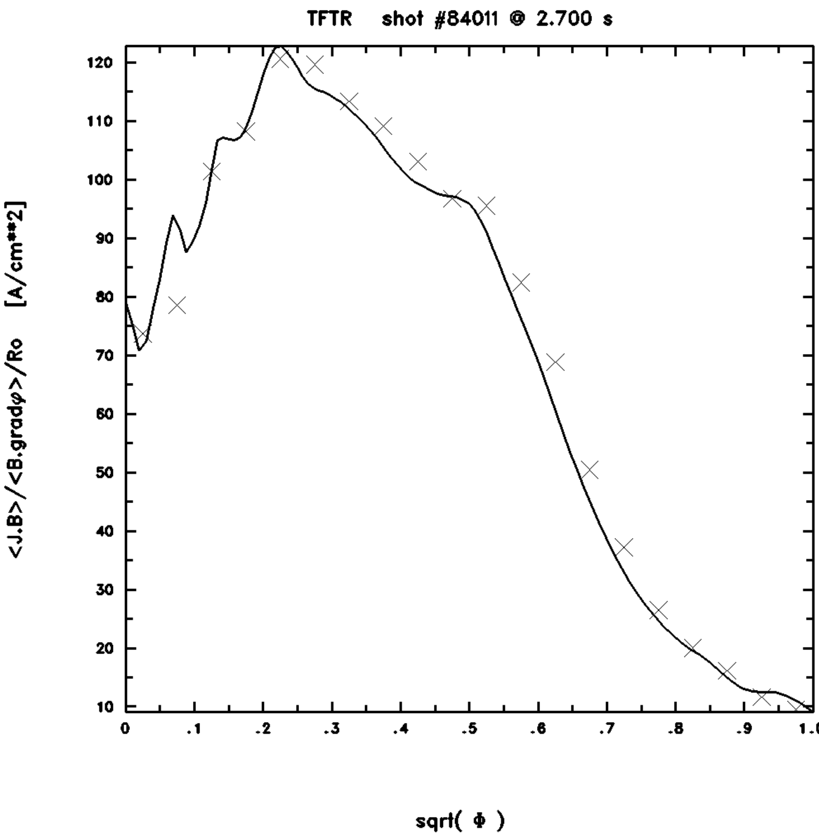
- **The differences in the centers of the flux surfaces is large for high-pressure, reversed-shear discharges**
- **This apparently arises as VMEC uses the toroidal flux as a variable with a grid which is coarser than CORSICA**

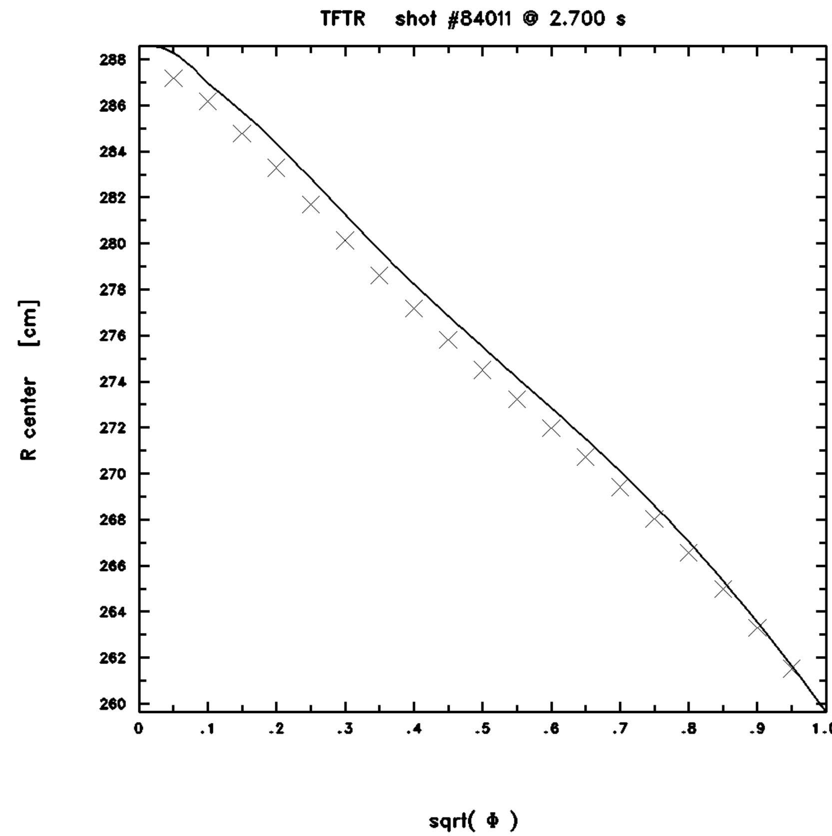
transsp run 84011w04



Calculated current density, flux-surface centers

- **The VMOMS MHD option in TRANSP uses $\sqrt{\text{toroidal flux}}$ as a variable; Corsica agrees much better with it than with VMEC**





transp run 84011w03

CONCLUSION 2 – Neoclassical resistivity yields good agreement with the data in calculations of the current profile evolution

Here we use TRANSP neutral beam current drive and bootstrap current

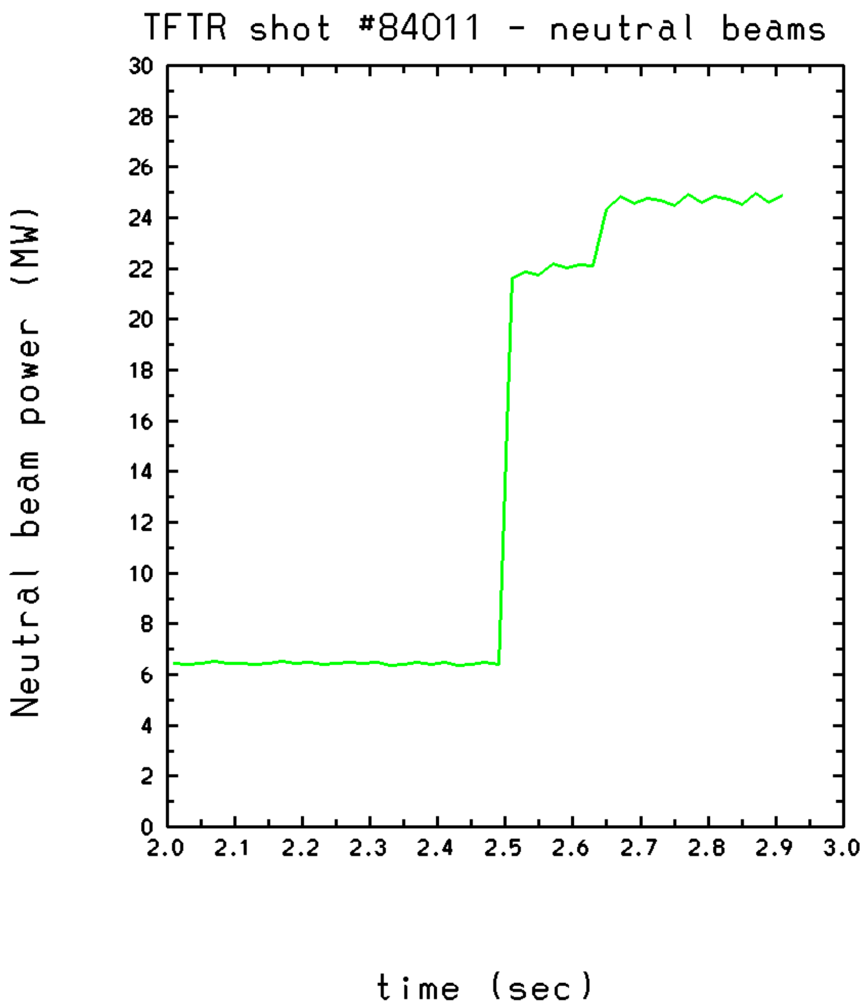
Input data includes:

- **Initial profiles of current, kinetic pressure from TRANSP**
- **Time dependences of kinetic pressure, densities, temperatures, Z_{eff}, current drive by neutral beams and bootstrap current from TRANSP**

Corsica calculates the time evolution of the MHD profile including neoclassical resistivity, ohmic current, etc.

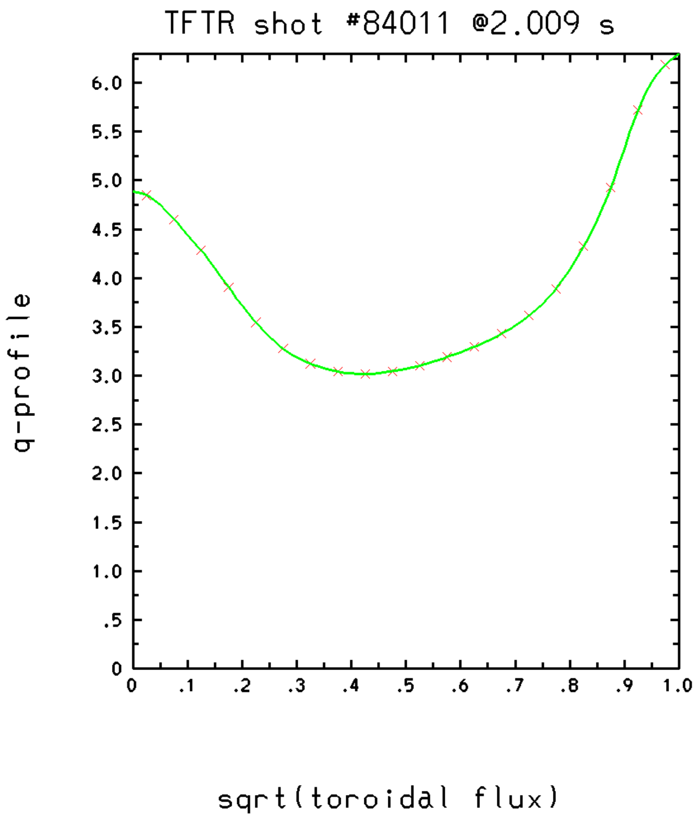
CORSICA integrates forward in time from an initial equilibrium; we start our calculations at t = 2.01 seconds

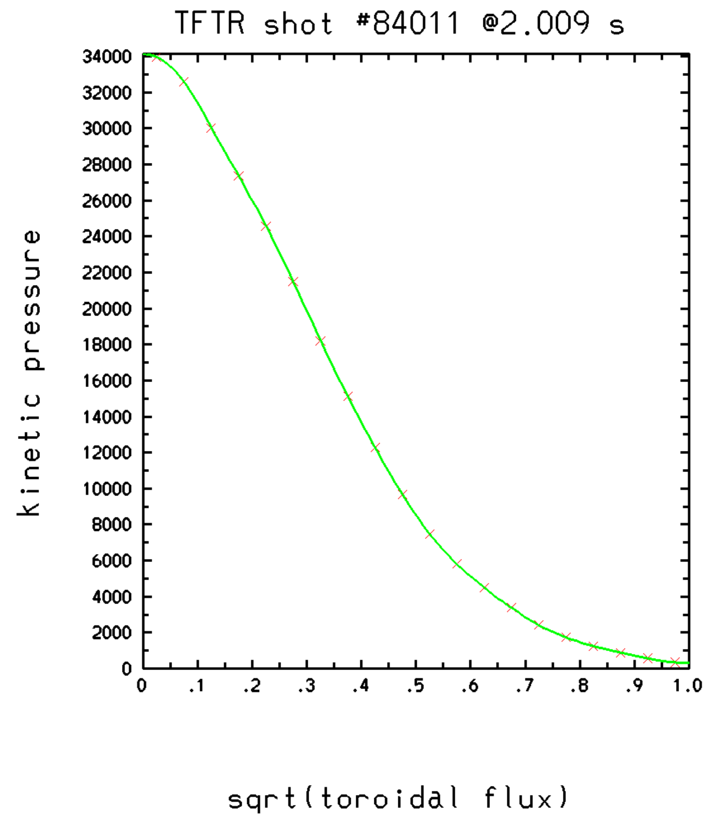
TFTR - Neutral beam history for reversed shear discharge



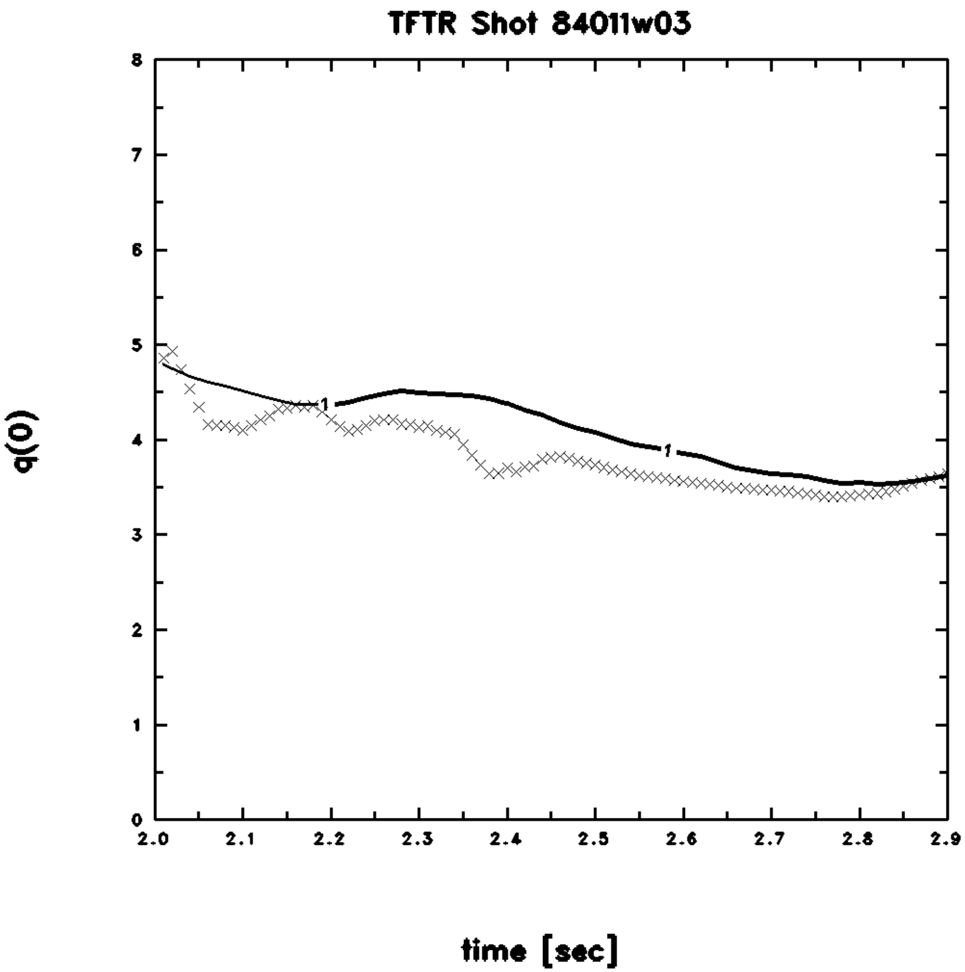
Initial conditions for CORSICA

- We start the CORSICA runs at 2.009 sec using TRANSP 84011w03
- MHD equilibrium uses the q-profile and kinetic pressure for initial currents
- × - points are the data; lines the CORSICA initial fit





Time history of safety factor (on axis) using TRANSP kinetic pressure

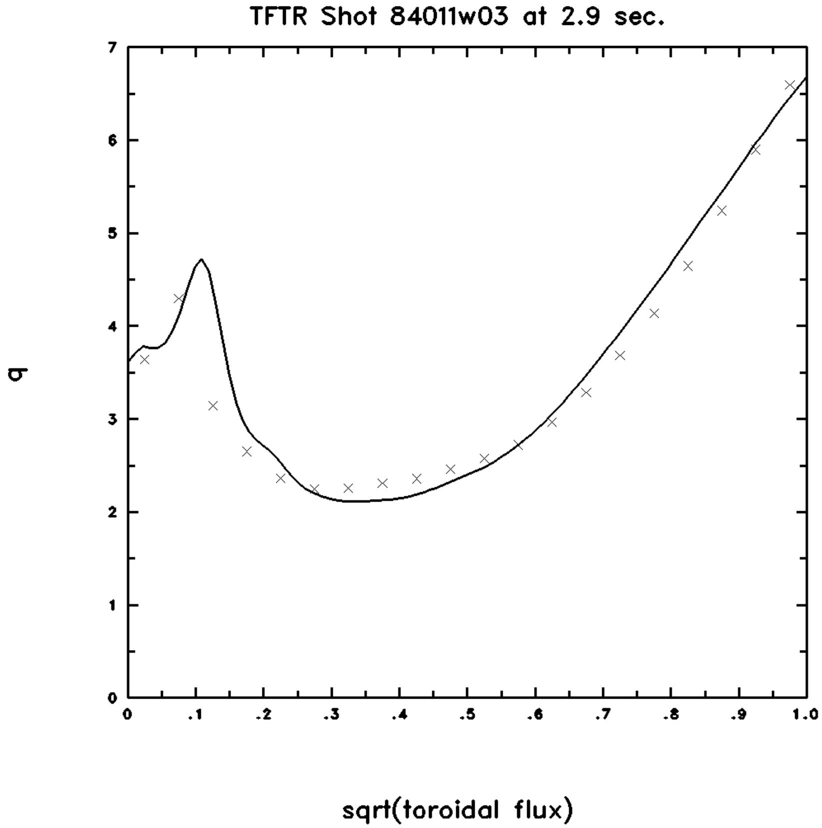


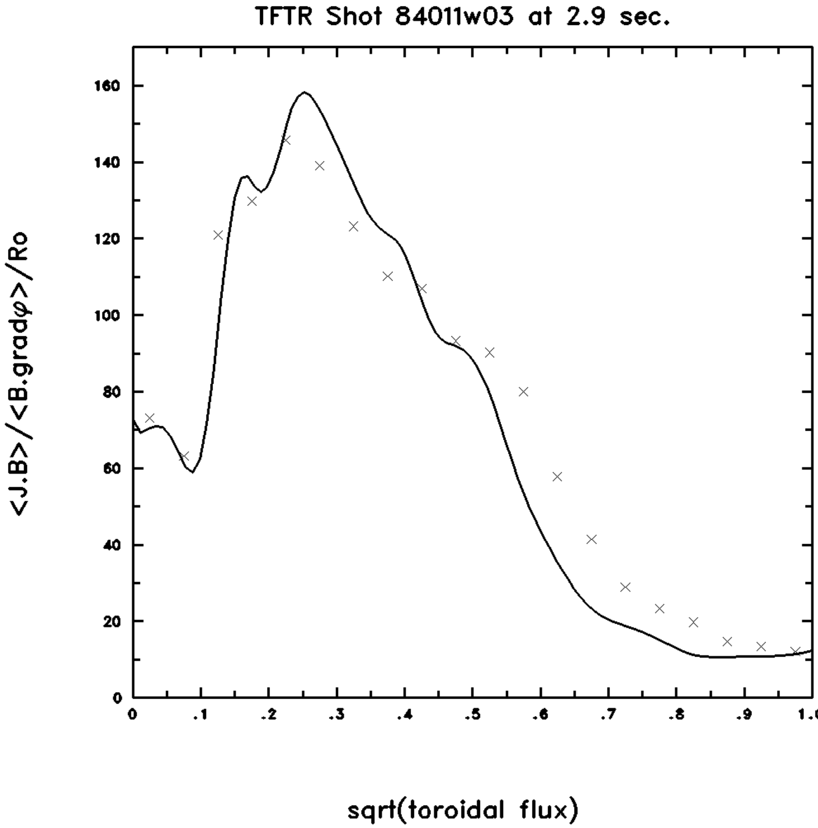
Neoclassical resistivity models the current diffusion well, including the high-power part of the discharge

Note that the MSE is blinded after 2.5 s when the beam power is raised, thus increasing the uncertainty in the measured q-profile

Calculated q and current density profiles agree well with data

- Evolution followed from 2.0 seconds to 2.9 seconds
- × - points are the data; lines the calculation
- Similar calculations for DIII-D also show good agreement (Tom Casper)





CONCLUSION 3 – Neoclassical resistivity, neutral beams, and bootstrap current, as modeled in CORSICA, yield good agreement with the current profile data

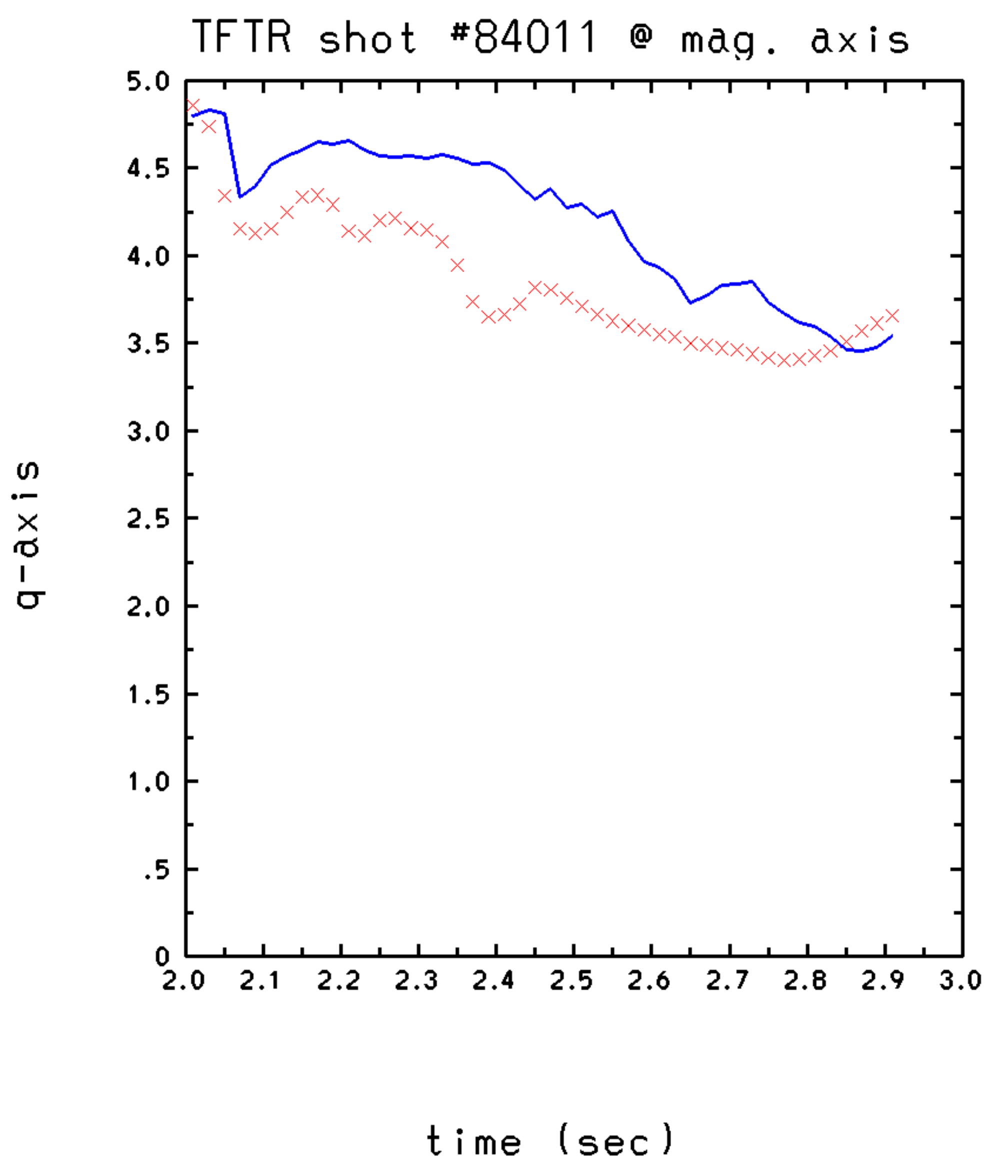
Next, we repeat the current profile evolution including calculated neutral beam injection, energetic ion orbits, and the resulting current drive

Bootstrap current is included using a neoclassical model

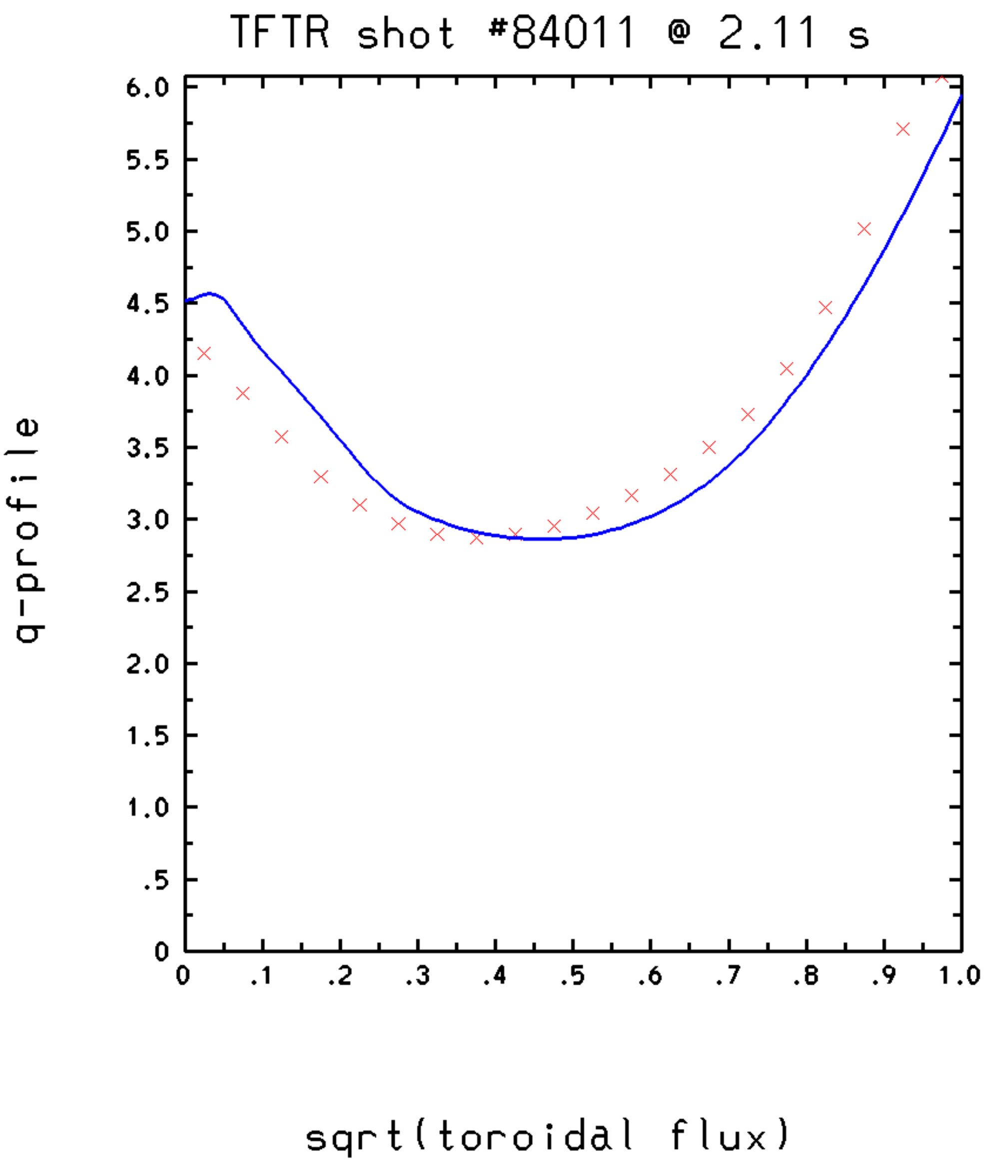
However, the L/R time of the plasma is long enough that this is not a sensitive test of these models — Essentially, the ohmic current adjusts in the direction to reduce the effects of small errors, e.g. in the energetic ion model

TFTR -reversed shear discharge – Time history of q0, calc. with NB and bootstrap drives

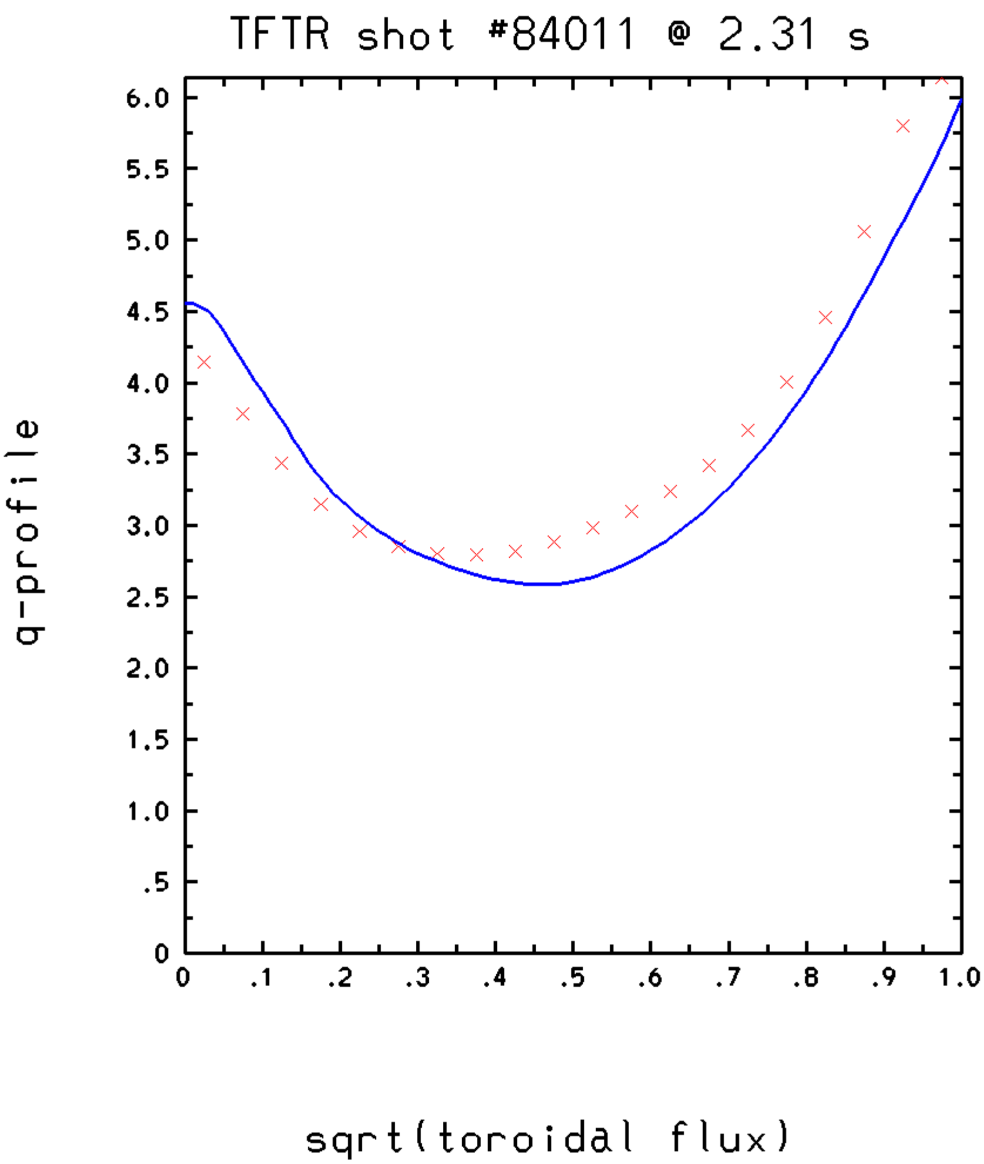
- **The agreement with data is almost as good as that using the NB and bootstrap drives determined by TRANSP (see earlier figure)**



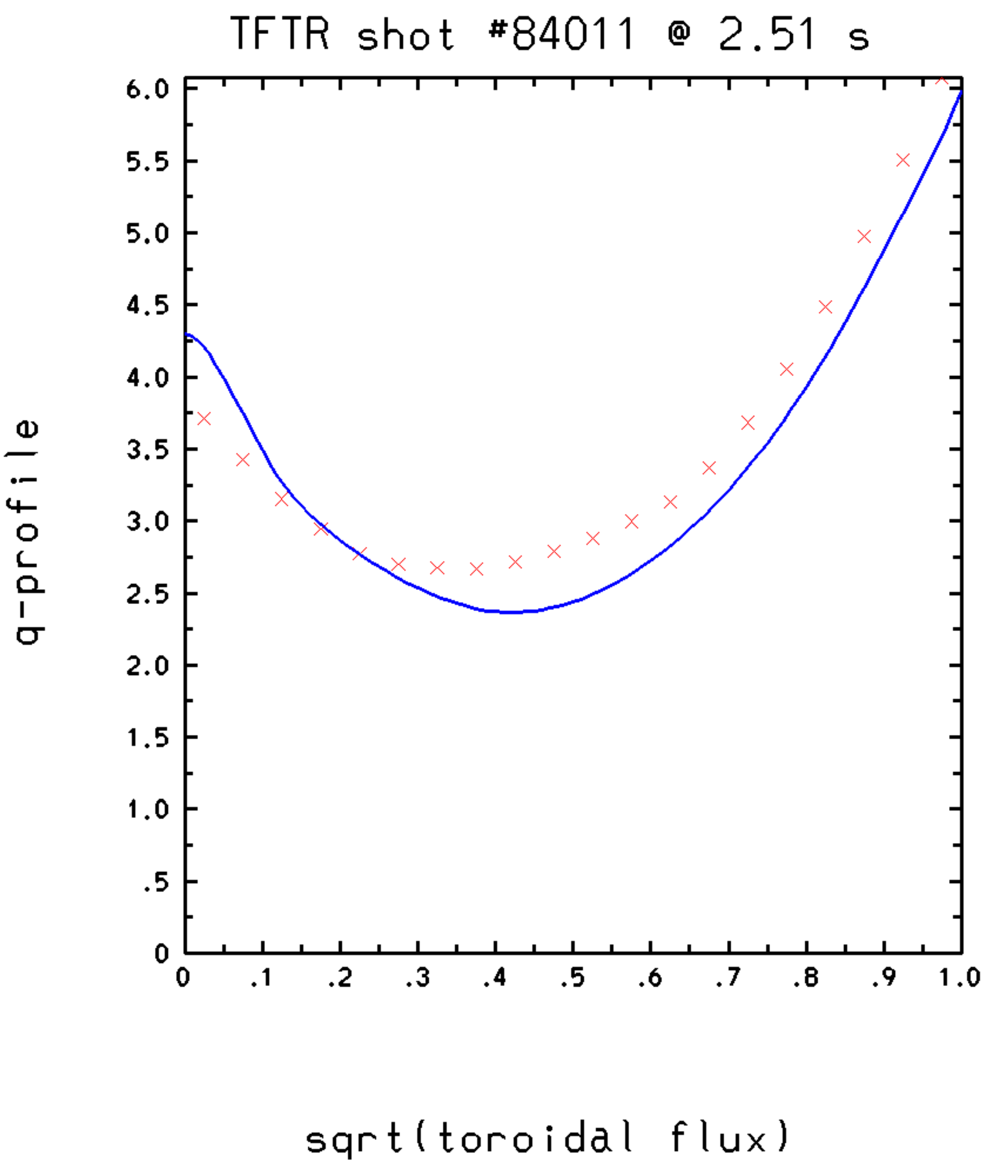
q-profile at 2.11 s evolved from 2.01 s



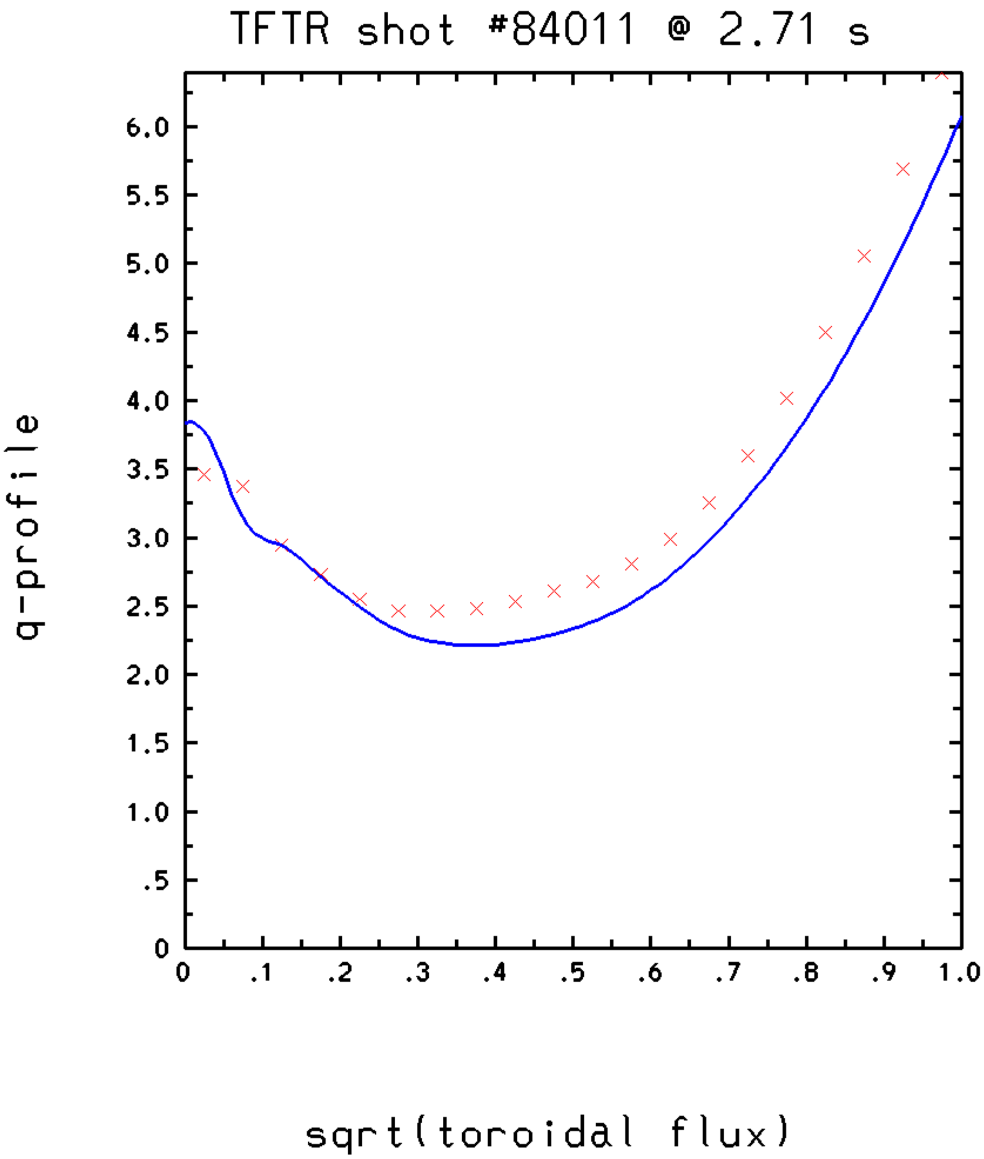
q-profile at 2.31 s evolved from 2.01 s



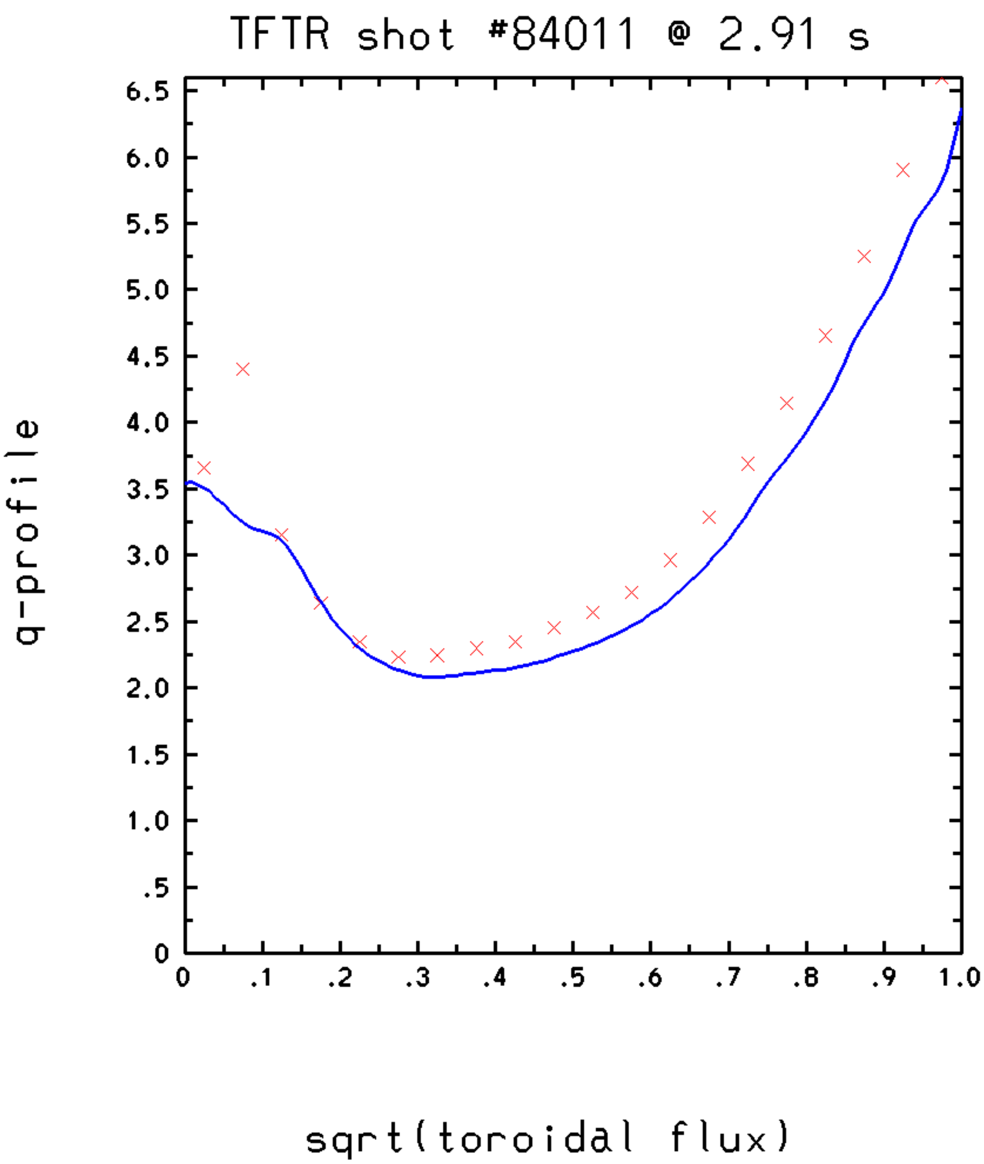
q-profile at 2.51 s evolved from 2.01 s



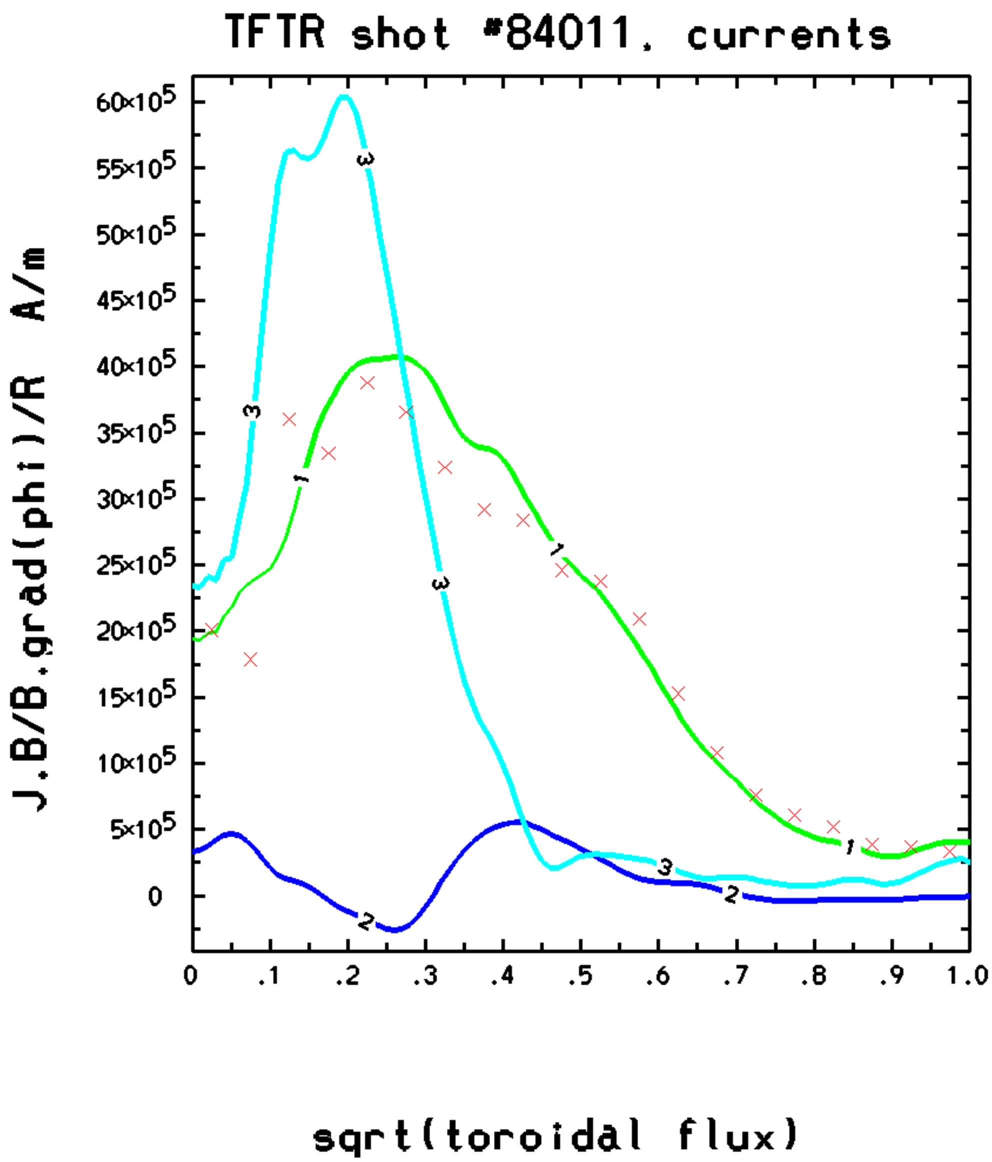
q-profile at 2.71 s evolved from 2.01 s



q-profile at 2.91 s evolved from 2.01 s



TFTR -reversed shear discharge – Discharge currents including NB and bootstrap drives



Time = 2.91 seconds

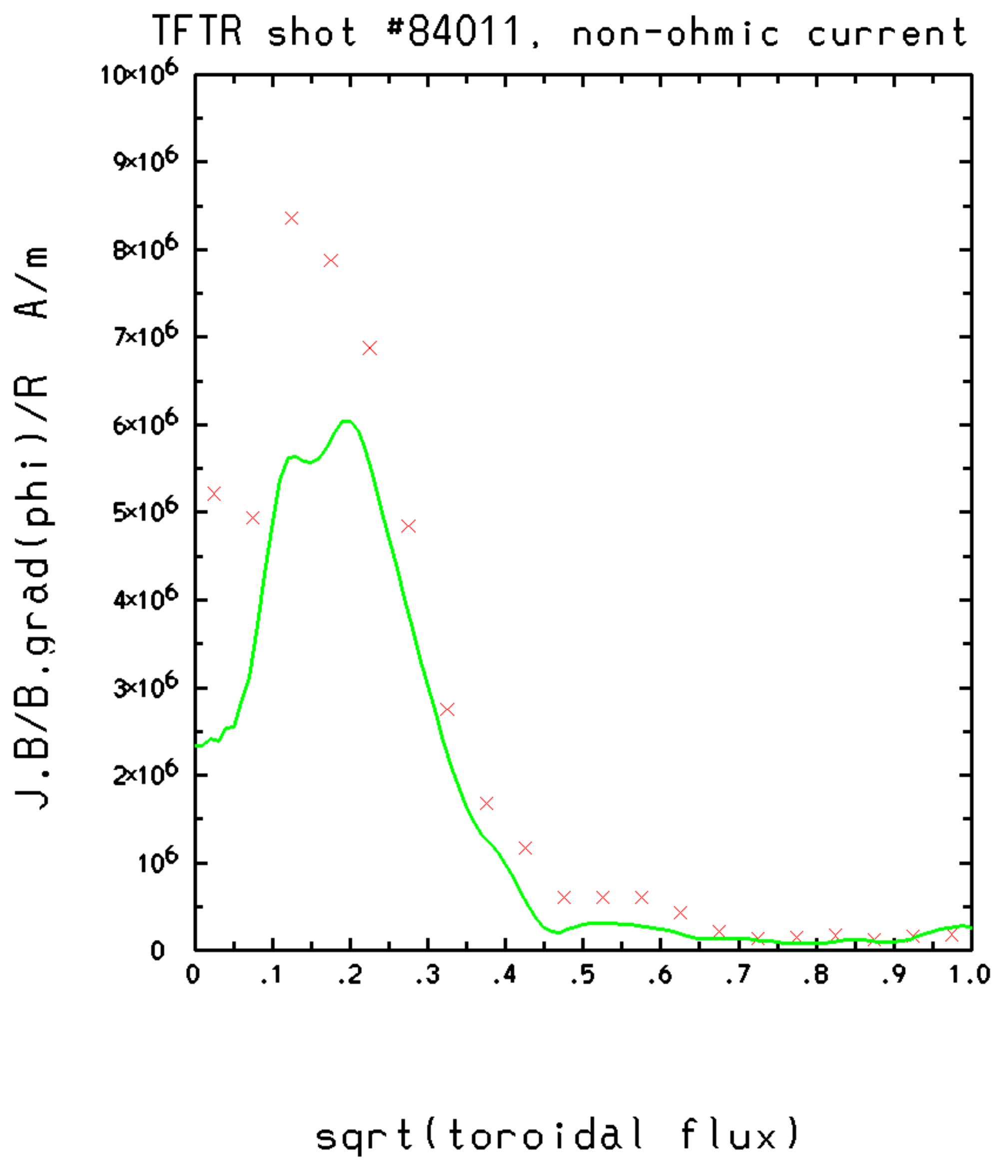
#1 (green) **Total current**

#2 (blue) **Neutral beam driven current**

#3 (cyan) **Bootstrap current**

crosses **Data for total current**

TFTR -reversed shear discharge – Driven currents including NB and bootstrap drives



Time = 2.91 seconds

Summary

- Current profile evolution in reversed-shear discharges is modeled well by CORSICA

  - The profile is dominated by the slow current profile evolution
  - The CORSICA models of bootstrap current and neutral beam current drive are in fair agreement with the deductions by TRANSP
  - Similar conclusions are reached in modeling DIII-D discharges (Tom Casper)

- Results near the magnetic axis are sensitive to the combination of the analytic behavior and grid resolution for the “radial” variable

CORSICA is a versatile tool to analyze the contributions to the current in reversed shear discharges and to predict the behavior of the current evolution in planning experiments